GASH RIVER FLASH FLOODS CHALLENGES TO KASSALA TOWN: MITIGATION AND RISK MANAGEMENT

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Received Nov. 2010, accepted after revision Jan. 2011

ABSTRACT

The Gash River originates from the Eritrean Highlands and the Ethiopian Plateau. It is a seasonal flashy river with high variation in flow during the wet season. It has a catchment area of 21000 km², a river length of 200 km and a slope of approximately 200 cm/km. The mean annual discharge is 680 million cubic meter. The river basin experiences considerable socio-economic activities, environmental issues and flooding of approximately 1 in 5 years. The River Gash is a source of frequent terror to the inhabitants on both sides of its banks especially the Kassala town, which is very severely attacked by several damaging high floods. Almost half the city was washed out by the most damaging flood of 2003.

This paper examines the history of the river behavior aiming to identify the main causes of flood risks and banks failure due to the floods. The paper will also review the structural and non-structural efforts to combat the flood damaged and manage its risks. Therefore, the protection works constructed on the river course to protect the city and the agriculture farms is discussed. The causes of the 2003-year damaging flood and its negative impacts are thoroughly studied. The lessons learned are reported. The paper concentrates on the non-structural methods for flood risk management, uses space technology in identifying the flood damage potential, and discusses the means and modalities for risk management, preparedness and warning systems. Attempts to find ways and means for mitigation measures pointed out.

Keywords: River, Floods, Flood risk, Flood management, Kassala
1. INTRODUCTION

Sustainable development and management of Seasonal Wadis requires reliable and properly analyzed data. Long period monitoring of Wadi discharge is essential as well as other information including, meteorologic, topographic, structure and soil.

Historical hydrologic data is very limited [1]. The major limitation of the development of Wadi hydrology in arid zones is the lack of high quality observations [2] especially rainfall and evaporation records. Remotely sensed data can be used to supplement the limited available observational data to bridge this gap. Satellite technology provides some real potential for comprehensive rainfall and evapotranspiration monitoring in space and time; however, most of the satellite rainfall estimation techniques are still experimental and require further research, in terms of calibration and validation. UNESCO is making great effort through different programs to operationalize the use of modern technologies in managing arid and semi arid zones water resources (IHP [3], GWADI [4], etc.).

Gash is the main source of water supply for all purposes to Kassala and its surroundings. It is the only recharge source to Gash groundwater basin. Gash is also the source that created the delta (300 thousand feddans) that has the most fertile land for agriculture on which most of the Kassala socio-economic activities depend. People say that without Gash there will be no Kassala.

Kassala town whose population is more than ½ million was the most affected town by the Gash flooding. It had been attacked by several damaging high floods from the Gash River most of which were very severe. In the last three decades, the town was attacked by six devastating floods recorded in the years 1975, 1983, 1988, 1993, 1998 and 2003. The most damaging one occurred in year 2003, where almost half the city washed out. The total loss is estimated to amount to 150 Million US$. The River Gash is considered a source of frequent terror to the inhabitants on both sides of its banks. Figure 1 shows the location map of the Gash River and its terrain. It can be seen that almost all the catchment area of the Gash River lies outside the Sudan in a hilly terrain. This calls for collaboration and corporation with neighboring countries, which is currently not available.

2. Gash River Behaviour

In Eritrea 20 km south Asmara, the Gash River; called Mareb; has a catchment area ranges from 30 to 90 Km in width and approximately 250 Km in length. The first 175 Km is perennial while it becomes ephemeral before it enters Sudan. The catchment area is estimated to be about 21,000 km². The river characteristics in this area are sandy bed with varying width and well-defined banks (one to two metres high). The bed slope of the river is varying with average of 2m per km. Before entering Sudan, the river passes a narrow rocky course while the flood plain is populated with dense palm trees.

From morphological point of view, the Gash River is considered braided river. Thus, it becomes wider and shallower. In such rivers, the flow takes many directions resulting in unstable river that changes its course.

There is no reliable rainfall data available in the catchment. Generally, in the Kassala area the climate is a tropic continental type. It is governed by the dry north wind in the winter and moist south wind in the summer. The temperature ranges from 16 to 42°C and relative humidity ranges from 40 to 60 %. Geologically the area is Precambrian basement complex, while Kassala and Mokram hills represent the main out crops of the basement complex. Furthermore, the other formation is the clays of the plain, consisting of a maximum of 18 metres thickness on the east and west sides of the river. The alluvial deposits formed by the Gash are the third type of formation with a thickness ranging from 17 to 34 metres.
The discharge measurements of the Gash River, which go back to 1907, are showing high fluctuation. Figure 2 shows the total and maximum-recorded discharges for the period 1907 to 2003 at Kassala gauging station. The minimum annual total discharge is 140 million m$^3$ recorded in 1921, while the maximum annual discharge is 1430 million m$^3$ recorded in 1983. Year 1983 is the year before the peak of the drought in 1984, which stroke the African countries during the eighties, in particular Ethiopia and Sudan. It is clear that the maximum annual flow is almost 10 times the minimum one, indicating the high variability of the flows in Gash River. However, the minimum instantaneous discharge is 170 m$^3$/s in 1921 and...
the maximum one is 870 m$^3$/s in 1983. The flow in the Gash River can start with only trickle move and reaches more than 850 m$^3$/s in a very short time. The annual average flow is 680 million m$^3$. According to the available records, Figure 2, the following years experienced famous floods events, which have damaging nature to the whole valley, especially the Kassala town (1921, 1926, 1927, 1929, 1931, 1932, 1939, 1941, 1950, 1952, 1973, 1974, 1975, 1983, 1988, 1992, 1998 and 2003). The 1975 flood is one of the most damaging floods and of catastrophic nature. However, the 2003 flood was more serious when compared to that of 1975.

It worth noting that there is only 30 km distance for the Gash River to pass from the Sudanese-Eritrean border to reach Kassala. This leaves only about 4 hours for the flood wave to reach Kassala, which is not enough for warning and preparedness.

3. HISTORY OF THE PROTECTION WORKS IN THE GASH RIVER

The protection works in Gash River around Kassala town goes back to early last century. A protection embankment is constructed on both sides of the riverbanks on a length of 10 km to protect Kassala town. Also spurs at 500 m spacing were constructed to combat lateral movement of the river flows and force it to transport its sediment downstream the protected zone. These spurs and dykes were very efficient in keeping the river channel in the Kassala reach since 1931 as compared to other unprotected reaches [5].

As mentioned above, the main purpose of these set of structures is to direct the flow towards the centre of the river course and hence force it to scour the bed i.e. direct the flow away from the bank. This will allow the water stored between the spurs to slow down and deposit its sediment, which at the end strengthen the banks of the river. The disadvantages of this system:

i- It is expensive.

ii- It requires very high engineering experience. Especially when determining the length, direction and spacing between the spurs.

iii- It requires regular maintenance.

Several methods of riverbank protections were used in the Gash River valley. One of the most well known structures is the groynes system as shown in Figure 3.

In case there is any damage or breakage in any of the spurs, the whole system will be affected and may totally collapse. The later might cause negative impact on the entire system of the river course. Therefore, riverbank failure may follow, leading to what has happened in Gash River during the flooding of 2003.

The sequence in which these spurs and dykes were constructed is as follows:

Seven spurs were constructed downstream the Kassala bridges in 1931 to 1937 some of which were completely silted. Another seven spurs were constructed during the period 1976-1984 with some spurs silted. Seventeen spurs were constructed in period 1984-1998. Thus, 31 spurs were in place however, Kassala town was hit severely by the 2003 flood.

4. SEDIMENTATION IN GASH RIVER

The Gash River although is seasonal, however, it has high impact on its valley. Gash River seems to carry an exceedingly large charge of sediment [6]. Recent measurements and estimation of the sediment load showed enormous variations where the highest value exceeded 70,000 ppm. This is compared to the highest recorded sediment concentration of 9,722 ppm during the fifties [6]. The sharp increase in the sediment (8 times) shows the
serious effect of the recent drought years (during the eighties) on the Gash River catchment area. At the same time, it has a negative impact on the magnitude of the flood and its damaging capability. Assessment of sediment in Gash River course indicates that a huge amount of sediment has been deposited along the bed with variation in its thickness (1 to 3 metres), especially near and under the Kassala Bridge, which acts as a bottleneck obstructing the flow. Some observers attribute the last flood impact on Kassala town to the obstruction of this bridge to the river flow. The Author of this paper agrees that existence of the bridge with its low deck is one of the reasons aggravating the situation during the flood of 2003.

5.  **BANK FAILURE**

Generally, there are four causes of bank failure, namely, toe failure, abrasion failure, seepage failure and saturation failure [7]. Toe failure occurs when the scour undermines the bank stability resulting in sliding and loss of bank material. Abrasion failure occurs in fast flowing erodable rivers. Seepage failure occurs due movement of seepage from landside to the river. It also occurs when the neutral pressure increased or the intergranular pressure decreased. Saturation failure is usually caused by rains and/or overtopping of the banks.

Three out of the four causes of bank failure except the abrasion failure were experienced in the river Gash [7].

6.  **RIVER BED LEVEL RISE**

Downstream of the bridge, the Gash River widened and silted [7]. Cross-sections taken in successive years of 1971 to 1974 showed 40 cm rise in bed in the downstream side. Comparison of the bed level of 1936 with that of 1974 at the same location revealed 380 cm rise in bed. It can be seen from these studies that there is a bed rise at a rate of 10 cm per year downstream of the bridge. A survey in 1976 revealed that the Gash riverbed level at the downstream side of the bridge is on average 10 cm higher than the ground level of the Kassala town. This indicates a clear design and construction systems adopted in training and protection works in this zone, which is mainly dry pitching.

7. **CAUSES OF FLOODING IN KASSALA TOWN**

The Higher Technical Committee for Gash River Training and Kassala Town Protection on their report of 2003 [5], concluded that flooding of Kassala town could strictly happen if the embankment failed and attributed the failure to:

- Increase in water levels of the river
- Cavitations due to human and animal activities on the embankment and river banks
- Direct scour of the embankment by water currents and waves

Rise in water levels can be caused by increase in the river discharge attributable to climate change, which lead to land use change, and eventually to high floods and sediment transport. Human activities on the riverbanks led to control the river from natural expansion in its flood plain. Dam failure in the upper catchment area also contributes to rise in water levels of the river.

Another prime cause of rise in water levels in the river is the reduction of its channel carrying capacity caused by the structures obstructing flows such as bridges, spurs and dykes. In addition, some morphological changes such as rise of riverbed and change in slope have its contribution in river water level rise.

Cavitations happen due human and animal activities or weakening of the embankment. The direct scour of embankment can happen due to
the steep nature of the Gash river which leads to high-speed flows bearing in mind that the embankments are sandy and have no resistance to such high waves.

In the 2003 flood, there are many factors worked collectively to produce the catastrophic flood of 2003. Some of these factors have cumulative nature while the others have instantaneous effects. The river flow was tremendously increased following high rainfall over the upper catchment. Around Kassala the existence of the two bridges constituted obstruction to the flow. The channel carrying capacity under the bridges is estimated as 400 $\text{m}^3/\text{s}$ compared to an estimated flood wave of 700 $\text{m}^3/\text{s}$. This lack of carrying capacity led to fast water levels on the back of the bridges to overtop the embankment, scour it from the back and demolish it with aid of the failure of the spurs that allowed the water current to directly strike the embankment. The difference in pressure on the two sides of the embankment contributed greatly in the failure of the embankment. No early warning system is in place so that people get prepared to the flood in addition to the bad drainage system in the town the accumulated Gash water is not drained at the required speed.

8. LIVING WITH FLOODS

There are many ways to reduce flooding risks. Choice among these methods depends on the cost, the community’s vulnerability to flooding, the extent of existing development and available funding. There are two types of risk reduction methods commonly adopted worldwide which can be applied to the Gash River namely structural measures and non-structural measures.

i- Structural measures: - involve constructing physical works designed to contain floods and limit erosion from the river-such as stopbanks, rock linings, revetments, gabions, groynes and vegetation buffers. This was practiced in the protection works existing in the Gash River. This category also includes building proofing against floods.

ii- Non-structural measures: - include land use planning regulations and voluntary actions, and steps that could be taken to prepare for floods. These measures aim to keep people out of the flood prone areas and improve the community’s ability to respond to and recover from floods. Non-structural measures also include early warning system complete with communication system and emergency preparedness. Non-structural measures enable a community to be more resilient to flooding through flood awareness, preparation and sensible land use.

Structural and non-structural measures are equally important management approaches for the Gash River. The ultimate should consider both (structural and non-structural) in an integrated way to reduce flood hazard effects.

9. EARLY WARNING SYSTEM

As stated above the catchment of the Gash river is completely outside Sudan and that the floods wave needs only four hours from the border to reach Kassala and may be only two hours from the first gauging station inside Sudan (Algira). This makes the early warning systems that depend on real time data ineffective. This fact also paves the way for warning systems that depend on remotely sensed data and calibrated CCD-RFE models.

The procedure to establish an early warning system comprises the following:

- Develop a reliable rainfall estimate methodology with suitable lead-time such as USGS-RFE, CMORPH, MM5 etc.
- Calibrate a suitable rainfall-runoff model (distribute or semi distributed) to the real time data
Verify the calibrated model on another set of data which is not used for calibrating the model

Develop an updating procedure based on the calibrated model forecasts and the observed data.

Operationalize the system to serve as real time forecasting tool.

Such system in place will insure river flow forecasts with suitable lead-time to backup the flood preparedness, early warning systems and the structural efforts to protect Kassala.

Some efforts were exerted on modeling the flows in the Gash River using remotely sensed data. The results were very promising [8]. Figures 3 and 4 show the modeling results in the calibration and verification periods. In their study, they used the USGS Geospatial Stream Flow Model (GeoSFM) developed by USGS [9] and [10].

USGS HYDRO1K database (derivative of the USGS digital elevation database) was used to delineate the basin boundaries and stream networks and embeds topological information in digital format of grid cell resolution- one kilometer [11]. USGS Global Land Cover Characteristics Database [12] together with the FAO soil data were used to portion rainfall incident on a basin to surface runoff and water infiltrating into the soil. The GeoSFM model soil parameters were extracted from digital soil map of FAO [13] using SCS methods [14].

The rainfall estimates were obtained from NOAA FEWS RFE [15]. These estimates of gross precipitation input to each basin were prepared from METEOSAT thermal infrared images and ground based rainfall stations; 0.1 degree latitude/longitude grid at 1-km resolution [16]. The evapotranspiration data is derived from daily accumulations of six hourly data of NOAA Global Data Assimilation System (GDAS) and a Penman-Montieth evaporation method utilizing the USGS Global land cover for plant canopy resistance [17].

10. Lessons Learned

Based on the Higher Technical Committee report, the protection systems need continuous monitoring and maintenance otherwise small whole in the embankment or the spurs can lead to a very serious consequences.

The structural measures of flood control gives false feeling of safety and make people reluctant to make evacuation decision. This clear from attitude of population towards the evacuation calls.

Structural measures alone can only alleviate the flooding problem but cannot control it as the design of such protection cannot cover all the flood ranges because otherwise it will be cost protective.

Non-structural measures need collaboration with riparian countries and collective efforts towards watershed management as the major runoff productive part of the basin lie outside the Sudan territory.

Human activities in the flood plain are the main source of problems to the protection systems. This is clearly seen in the report of Higher Technical Committee.

Without awareness, regulations and participation of the communities in all stages of flood management systems, the project will not be a successful one. By doing so, ownership will develop bringing about the success.

11. Conclusions and Recommendations

It is clear that better and proper understanding of the Gash River behaviour is essential, before
embarking on the design and construction of the river training works. Structural and non-structural measures should be taken into consideration in any future solution for flood management in Gash River Valley.

- Establish good collaborations between Sudan, Eritrea and Ethiopia to consider basin management of the river Gash

- More attention should be developed to the river discharge measurements and early warning system with an upstream station at Tessanie (inside Eritrea) should be established.

- The responsibility of the Gash River flood management should be clearly determined. It is preferred that the Ministry of Irrigation and Water Resources be responsible for the whole system including the Operation and Maintenance. Excellent engineers are highly recommended, since sometimes-important decisions have to be taken at the site without any delay due to the nature of problems.

- The problem of sediment should be under focus and more attention should be given to sediment assessment and monitoring.

- Intensive future researches and studies are highly recommended in the Gash River Valley, particularly in the flood management area to protect the Town and the Gash Irrigated Scheme.

![Figure 3: Observed and simulated discharges of the Gash River during the Calibration period](image)

Figure 3: Observed and simulated discharges of the Gash River during the Calibration period
Figure 4: Observed and simulated discharges of the Gash River during the verification period

References


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